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ABSTRACT

This brief seminar presentation for parents and child minders points out aspects of brain development in human infants and provides answers to questions asked by seminar participants. Basic facts of anatomy, including the development of micro- and macroneurons, nerve cell migration, sprouting synapse formation and the death of brain cells are related. The extent to which brain growth is determined by infant activity is emphasized, as is the necessity of protein input especially in the first two years of development. Three aspects of sensation/stimulation are discussed: the role of external sensation and stimulation, critical periods of development, and occupational therapist Jean Ayres' theory of brain development in children with learning disabilities. In conclusion it is emphasized that the sensory world of the average child in Sydney, Australia, is sufficient to ensure normal brain development. Appended questions and answers focus on the issues of handedness, television viewing, drugs, alcohol and cigarettes. (Author/RH)

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# Selected Papers

## Number 2

## Unit for Child Studies

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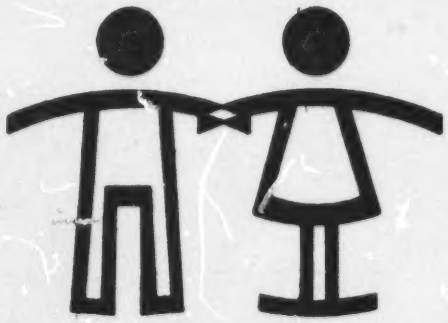

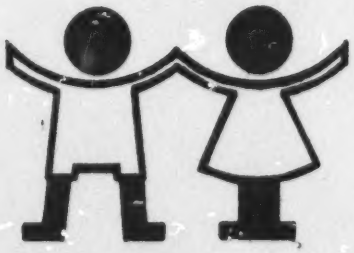

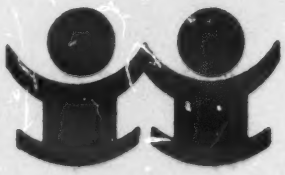

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# BRAIN DEVELOPMENT IN CHILDREN

DR CHARLES WATSON

# BRAIN DEVELOPMENT IN CHILDREN

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When I first became involved in the development of motor systems in humans, I felt a little inadequate in terms of my lack of knowledge of brain development because I had not picked up very much during the medical course that I did, and there did not appear to be much available to read.

What I found, after a few months of looking around (this became even more evident after a couple of years of trying to gather information), is that there is precious little hard information on brain development, both pre-natal and post-natal. In the last two years there has been a remarkable rise in interest, partly due to the availability of better techniques for studying the subject, but it is still pretty much of a wasteland in terms of solid information. For this reason, a certain amount of what I have to say may be different from what others might say because we have little islands of information, and a good deal of guesswork in between. My story sounds convincing to me, but I can't guarantee it is the whole truth from beginning to end. It is my version of how I think brain development runs.

The next thing I want to say is that because I normally talk to people who have some background in anatomy and biology, I sometimes slip into using terms you might not be familiar with. I shall try not to do this when speaking to you.

The significance of different processes of brain development in humans is underlined when you compare a new-born baby and a new-born grazing animal such as a horse; a new-born foal is, within hours, up on its feet and within days is reasonably strong, can control its balance; within a very short time, is a competent member of the herd - it can escape predators and so on. At the time of birth the brain of the animal has received appropriate genetic instructions to carry out almost all of the complex behaviours that it needs for survival and it achieves these comparatively quickly. Five years later it can still be taught to do various clever things such as how to jump better and suchlike; it gets larger but it does not behave much differently from the two-weeks-old.

Humans, and many other mammals (the primates in particular) of course, are in a completely different situation. At birth a baby can perform a relatively small range of behaviours. It can suck, it can grip, it can cry out, but it can not lift itself; it can not move itself around; it is completely helpless. But, at five years, it has been able to develop a fantastic range of behaviours, including communication skills. What one deduces from these comparisons is that the human brain (and this applies to a lesser extent to certain other mammalian brains, particularly the monkeys and apes) leaves a lot to the post-natal period and to chance. The genetically instructed parts of the brain provide a framework and then, after the baby is born, there is enormous opportunity for interaction with the environment around it for learning to go on, depending on what opportunities the baby has. It is how brain development is influenced by the surrounding environment that I wish to discuss.

The influence of the environment on the brain, particularly post-natally, can be seen fairly clearly, as far as the human brain is concerned, if you compare the genetic instructions (just on a numerical basis) with the number of

neurones. From what I recall of biology, there are about 80,000 genes that provide instructions for body development. The brain has $10^{12}$ cells - which is something like a million, million cells - with many orders of magnitude, and the cells are connected up in various complex ways. It is quite obvious that there is nowhere nearly enough genetic instructions to wire up every cell in the brain. What happens when nerve cells form is that they sprout processes to grow out towards others and, if they make good connections, they survive. If they fail they are deleted. There is an enormous amount of loss in the system where, in some cases, for example, ten times as many nerve cells are made as are needed, and they make 100 times as many connections as required by the individual - all the weak connections are eliminated later. In other words, there is enormous room for the nervous system to organise itself. It is not limited by particular instructions.

In pre-natal development, the nervous system is the first part of the body systems to be laid down. Very early (in the first couple of weeks), on the back of the embryo there is a groove that forms (like a little gutter) and this groove sinks down into the back to be converted into a tube that runs the length of the body. By about 3-4 weeks the front end of the tube starts to show various swellings. There are three main swellings at first. These form the main part of the brain. By the fourth week, when the embryo is only as big as a jellybean, the main parts of the brain have been laid down and the framework of the different portions of the forebrain, midbrain, hindbrain, and spinal cord are all there.

By about three months, all of the main motor and sensory pathways and the long connecting pathways have been laid down. The motor and sensory nerves and the long pathways all have in common the fact that they are formed by largely genetically-instructed neurones. These neurones are normally big neurones (we call them "macro" neurones, and the term "neurone", incidentally, is another word for a nerve cell). Once these macro neurones and their connections are laid down and established at this early stage, whatever the environment around them, they will survive under all circumstances whether deprived of stimulation or not.

This is quite different to the second group of nerve cells (which, reasonably enough, are 'micro'neurones and which Jacobson, an experimental embryologist, distinguishes as Class 1 and Class 2 neurones). Many of them are still developing after birth; they appear much later in pregnancy, somewhere between three and nine months. The micro neurones are made in much greater numbers and their connection and even their numbers are not nearly as closely genetically-specified. They are the "cannon fodder" for the brain's development. These neurones are particularly numerous in the two enlarged parts of the human brain, namely the cerebral cortex, which forms the larger part of the brain, and the cerebellum, a sort of miniature version of the crebral cortex that sits down the back of the brain stem. These two parts of the brain are very largely made up (98%) of micro neurones by the time they are formed.

Micro neurones do not have many genetic instructions and many of them die, but, because they are not instructed by the genes as to what to do, the developing baby trying to reach things, and trying to develop new skills, and trying to learn things, is able to capitalise on the flexibility of the micro neurone system in order to develop an enormous range of skills. It can thence be said that humans owe almost everything to their micro neurones. The complexity and diversity of human behaviour can be accounted for by the micro neurone system.

Before looking any more at the functions of these two types of neurones, I would like to turn to what is going on *inside* the brain in terms of individual nerve cells and their processes while the macro-micro-neuron development is taking place. There is a particular sequence that is fairly standard for the different parts of the brain.

The sequence of events which occurs for most nerve cell groups is this: First of all, in any one part of the brain, a few germ cell neurones (very primitive ones) divide very rapidly to form a cluster of neurones in that area; this is the first step in proliferation. Then, some nerve cells, once they have formed in a particular area, find it necessary (we presume under genetic instruction, or, it could be that they are attracted to some other nerve cell group) suddenly move on into some other part of the brain. This is a rather extraordinary process of migration. It is prominent in some areas of the brain stem, and, once these nerve cells arrive at their destination they stay there, and like the cells who have stayed in their original positions they start the sprouting process. The cells originally are round with a nucleus of genetic material or genetic instructions in the centre of them. Some of them start sending out various processes and these are usually much longer than the others, and called axons. This axon carries information away from the nerve cells. The remaining neurones may become very bushy like an oak tree with many branches. These branches collect information and are called dendrites.

Once the nerve cells have sprouted their dendrites and axons, they have the processess necessary to connect up, one to another, and the axons of some nerve cells approach the dendrites and start making connections, and this (which is the most important phase of nerve cell development), is the process of connection formation or synapse formation. The term "synapse" means a connection in the nervous system. An axon probes out, gradually sprouts, trying to grow from one part of the nervous system to the other, and eventually, by means of specialised swellings, makes contact with another nerve cell.

Some cells, with very big dendritic trees sprouting out from them, may have up to half a million connections coming into them, so that the complexity that is happening when the nerve cells are all sprouting out axons, and dendrites, and trying to make connections, is something akin to a bucket of worms trying to make multiple connections everywhere. Thus, an incredibly active process is happening in the brain at this period of development. There is a certain time allowed for the nerve cells to make connections. They say "Go!" and sprout out connections, which grow up in different directions, often quite random, and, after a specified period for particular parts of the brain (it might be up to a week), the genetic instructions say "Stop!" If the nerve cells have made strong connections, and they are firing because they are working properly, they are allowed to survive. Those that do not make strong connections die off. In some parts of the brain as many as 90% of the nerve cells are deleted.

Incredible as that may seem, you find that, although the child's brain and the brain before birth is much smaller than that of an adult, and although the brain cells are smaller, there may be many, many more cells than there are in the adult. Even after birth there is continuing cell death and from about the age of 20 onwards we are losing 20,000 cells a day in the brain. Perhaps, this is, in fact, an extension of what goes on in the embryo. Strong neurones are encouraged and kept alive by making more contacts, and weak ones, the ones that have not made decent connections, are deleted. Maybe it is an efficiency process.

As mentioned above, synapse formation occurs spectacularly just after sprouting has occurred (between 3 and 9 months) prenatally, but can continue to occur after birth. In fact, there is a lot of evidence now that a good deal of reorganization of synapses, probably a massive amount, can occur in the cerebral cortex and in the cerebellum after birth. The cerebellum, the part of the brain that controls co-ordination of movements (eye movements, etc.), which sits underneath the cerebral cortex, probably has all of its synapse formation occur after birth. A spectacular example of how brain growth is almost entirely determined by what you do is seen in the case of a baby who is wrapped up and never let move. In this situation the cerebellum would never learn anything. It would never learn how to co-ordinate movements. It would make a lot of synapses there,

but they would be of no use to you.

The cerebellum organises its connections every time a baby makes a clumsy, tentative gesture, and every time it tries to bring a cup to its face and tries to get its lips around it; it is programming those nerve cells with information until finally, they can take over and the baby says to itself "I want to lift up the cup and drink". And it does. This is the developmental process with all skilled movements, and, as adults, remains the same. Adults are capable of learning skilled movements, and if you have gone through the process of learning to play golf, you realise that if you practice your golf swing often enough, it does become an inbuilt sequence. Learning musical instruments is much the same; whole finger patterns, if you are playing the clarinet for example, come into play when you look at the notes; you don't have to decide where your hands are going to go - it has been programmed in.

One wonders, sometimes, how much programming space the brain has. Certainly very few people test it, and this applies to many functions of the brain; the more you exercise it, the more you try and teach it, the more it is capable of absorbing. I doubt that it is ever pushed to its practical limits.

In summary, it is the sprouting synapse formation and cell death - the efficiency pruning process - which characterises brains such as the human brain where a lot of development occurs after birth.

Can a brain atrophy through disuse? I guess it must. There would only be synapse formation sprouting, and the efficiency of cell death. If you are not making many of the neurones work all the time, and sit around drinking cups of tea on the verandah all day, you might not expect to have things working as well.

Now, let us consider food supply as far as the growth of the brain after birth is concerned. Because such an enormous amount of sprouting and synapse formation goes on, particularly in the first two years of development, protein input for the baby at that stage is absolutely vital. There are a lot of questions about vitamins, for example, but most people are of the belief that if you have enough protein you are alright. Twice as much won't necessarily make you twice as good, and certainly, as far as Australia is concerned, there are very few babies who are at risk because of protein malnutrition in those first two years of life. However, on the world scene, of course, up to half, and maybe even two-thirds, of the children in the world have deficient protein intake during those first two years. This is horrific because it means that something like half the children in the world are at risk of having poorer, and fewer connections, and a less efficient cerebral cortex than they otherwise could have. Their genetics have nothing to do with their ultimate intellectual capacity, but their food supply might. So, food certainly makes an enormous difference to growth during those years; there are also various arguments that particular diets and particular additives to the food, and, in some cases, removing foreign additives from the food may make a lot of difference to the way that the brain develops. From my reading, I don't know of any hard evidence to support the statement that different diets are going to make a particular difference to the way the baby's brain develops over those first two years.

During the first year of life the size of the brain increases three times; that is not because new cells are being added (cells are dying by this time in their thousands because they are being eliminated during the sprouting and synapse formation). The size doubles again in the next five years. There is a huge growth spurt during the first year, and it continues to grow rapidly during the second year of life; which is probably when most of the main connections of the brain occur. Of course, the possibilities for change through environmental stimulation continues on well into the 10th, 11th and 12th years of life, and, after that, things become more stable. Not that you can't learn anything more,

but the possibility for radical change in connections is diminishing.

There are three aspects of sensation/stimulation that I would like to discuss. The last couple of years of research on animal brains has shown that, probably, the main influence shaping the organisation of the inside of the brain, apart from the genes, is the external sensation. The various sensory systems are laid down fairly early and they probably start functioning in this order: the touch system and the balance (vestibular) system starts functioning at about three months (six month's before birth), the hearing system probably starts about three months before birth, and the visual system starts functioning sometime after birth; it is certainly not at the time of birth, but soon after that the eyes can function reasonably well. The input through these four major channels - touch, balance, hearing and vision systems - has an incredible effect on the shaping of the brain. We can see this by means of experiments that have been done on developing animals deprived of one of these sensations either by cutting the optic nerves, or, more simply, by putting black covers over their eyes during the first few months of life. What is shown very clearly is that sensory deprivation has drastic effects on the organisation of the brain, not just on the relevant pathways, but the other related parts of the brain. It almost seems that the genes throw up a host of cells which start to make random connections with one another, and then the influences (the sensations from outside), shape the ultimate pattern of connections in the brain concerned.

As far as most children in Sydney are concerned, that's fine. The sort of exposure, different sensations - the fact that they are cuddled, they hear what is going on around them, they are moved around - is entirely adequate for their brain to develop. Humans would not reach their present stage of development if there was not enough leeway for the brain to develop within a normal parenting situation. However, there is a parallel argument which says, if deprivation makes such a lot of difference, won't enrichment be terrific. There were some experiments by some researchers in California, who took rats out of their laboratory cages and put them into small rat farms with bridges, swings, and activity wheels, and they found that the cerebral cortex in the rats was thicker and there were more synapses, more connections. All the physical evidence was that their brains were better in a quantitative way, and out of this grew a very popular idea that started in California (as most things do!) that you had to expose your children to a barrage of sensations from about one month old in order to take full advantage of the possibilities for brain development. I think that this is a little like the protein input to the brain; once you have enough, more does not make any difference. Certainly, there is no evidence to dispute this.

As far as the rats are concerned, the explanation lies in the fact that rats in cages were used and these are deprived by normal standards. To give them a more stimulating environment was like giving them something like a normal rat upbringing. In other words, they were using normal rat brains and comparing them with deprived rat brains. Thus, there was a problem of poorly controlled experiments, and there is widespread agreement now, that that is so. Neuroscientists are as fallible as other people. If they see something that looks as if it would attract everyone's attention, they use it, and, I think, that was what happened in this case.

The second interesting thing I would like to mention that has come out of the research on the effects of sensations on the brain, is the concept of critical periods in development. In the cat's visual system, for instance, it has been shown that there is a period between three and five weeks after birth, some quite discrete two-week period, when certain visual stimuli must be presented or the cat will never respond to them. In other words, if you rear the cat and always hold it upright and keep it in a drum with only vertical stripes painted on it, and you keep it there for those two weeks, it does not matter what it receives

before or afterwards, it will never respond to horizontal stripes. You can test this by recording from the visual area in the cat's brain. Normally you find 50% of cells respond to vertical stripes and 50% to horizontal stripes, but with deprived cats you will find that almost none will respond to a horizontal grating when you wave it in front of them. Out of this has grown the concept that there are discrete periods during which a particular quality, not just quantity, of sensation must be available or a part of the brain development will never go ahead. Whether this applies as far as human development is concerned, we don't know. We don't know whether the critical periods might be longer, exactly when they are, and so on. We assume that during the first year it is particularly critical as far as sensation presentation goes, and you certainly see this in babies who are deprived of sensation, for example, through being given large doses of sedative drugs.

Babies unfortunate enough to suffer epileptic fits in the first few weeks of life sometimes have to be put on to huge doses of sedatives at various times, and these children, unless a lot of attention is paid to them, just lie there and because they are not cuddly babies the parents have to make an effort to expose them to the full range of sensory stimuli around them. Otherwise they can miss out on an almost permanent basis because some areas of their brain are never stimulated to develop adequately, and after that period there simply is not the possibility to do so. The idea of critical periods is still being argued about considerably, and one of the problems is that we have so few fragments of information about the development of the brain, that people tend to seize on anything that pops up. An attractive idea like the critical periods is certainly something that can be popularised very quickly.

The possibility that particular kinds of sensation are important, is a theory developed by a woman called Jean Ayres, an occupational therapist in California. Her theory has been that for some children (probably due to some abnormal development of the long pathways in the brain, or of the sensory input to certain areas of the brain) there is a limitation to the sensory effect on brain development. These children by the age of five, or six, or seven, will present themselves as children with reading disorders, or various other learning disabilities, because the appropriate sensations are not being received properly. The actual wiring has never been effective in those brains. She particularly thinks that it is the wiring between the cerebellum and the vestibular system (a balance/movement recording system) that may be affected in these particular cases and there is some fragmentary evidence supporting her theory. There is no hard evidence disagreeing with her theory. Certainly, if it is true, it is going to have mammoth implications for the education system, because between two and ten percent of the school population between the ages of five and eight could be described as learning disabled; they have normal intelligence but have an inability to learn, in certain areas, the way that the average child learns. This particularly applies to the reading disorders, although to a certain extent, to maths functions as well.

Jean Ayres would argue that it is simply a matter of their brainstem's sensory processes not being co-ordinated enough to be able to give ordered information to the cerebral cortex. In other words, what the cerebral cortex thinks about the information it is receiving is a jumble; that is why these children cannot sound out words, why they reverse "b's" for "d's", "dab's" for "bad's", and 47's for 74's, and so on. They are facing complete confusion. Now, with enormous effort, many of these children can overcome that problem, and, in fact, some of these very bright children can achieve very highly, probably because they have had to try so hard between the time they were six and ten, often at great psychological cost. They are often discouraged by the amount of effort that they have to put in, compared with their classmates, and they are also disappointed because they don't do as well as they think they should be able to. Jean Ayres' solution has been to expose these children to particular

programmes of sensory stimulation such as spinning them, brushing them, or providing movements that stimulate their balance centres.

The hearsay evidence that comes out of this is that it appears to work. We don't know how effective it is alone, and what needs to be done over the next three or four years is to find out if it works because there are nice, kind people helping these children and they are responding to the extra attention, or whether it is because there is something specific about the patterns of sensory stimulation that the children receive. This general approach, the sensory integrated therapy of Jean Ayres, is being used at the Prince of Wales Hospital in the Paediatric Rehabilitation Unit. It is also being used at "Threshold", a private learning disorder clinic, run by Jim Bates, on the North Shore, and they seem to have success with it. Neither of these two people claim that this is the answer, or that they are sure that everything they are doing is producing the results, but, it does seem to have some connection.

As far as what happens in the sensory world of the average child in Sydney, almost anything you do is going to produce results because the simple complexity of the world that faces most children in the interaction with their family and the people around them, once they are old enough to start going out and exploring, is more than enough for their brain to receive enough entertainment to develop itself. With a basis of some genetic instructions, the micro neurones set about the task of developing the possibility of a wide range of behaviours, communications, etc. It is certainly not a cause for worry, and, I think, the whole sensory enrichment debate that went on was an unrealistic situation to foist on people because many worry that they may be doing the wrong thing as far as their babies are concerned. The brain will end up developing well, almost in spite of what you do, unless gross alterations are made to the sensory world around the baby.

## QUESTIONS AND ANSWERS

### Left Handedness

Q. "Does left-handedness have any relationship to brain development as a whole?"

A. The brain is programmed to be normally left-sided dominant and, therefore, the left hand side of the brain controls the right hand. I shouldn't say "normally" because the percentage is about 90%. Right dominant brains in left-handed people have a remarkable number of differences because it is not simply a reversal of function. There are marked differences and this may be a good thing because there is a lot of evidence for genetic processes throwing up different variants that have different capabilities and possibilities. What we do know, is that a rather delayed direction to the brain, where handedness is late in developing, can be associated with learning disabilities and with other abnormal processes in the brain. All that we know is that there is some vague tie-up between abnormal cortical development and definitive handedness formation, but I do not think there is any indication of how the tie-up might occur.

Visual Stimulation

Q. "Is T.V. a good visual stimulator?"

A. Well, there is nothing different from the visual stimulation of TV from the visual stimulation of any other. What *is* different about the children who sit and watch TV all the time is that they do not get the movements, kinaesthetic sense, that other children do. I think this is very important. Movement sensation and touch sensation is of incredible importance during those first few years, and, I think, it is important beyond that for the well-being of an individual. One of the reasons people enjoy jogging, or playing games, is that it is enjoyable and it makes you feel good. I think that well-being, particularly during those first few years of life may be greatly influenced by the available opportunities for movement (which involves touch sensation, of course) and, I think, one's ability to enjoy these sensations depends on the opportunities you have at an early age. Thus, one could say, that because of this, watching TV is not really beneficial.

Drugs, Alcohol and Cigarettes

Q. "Is there any evidence that drugs and alcohol and cigarettes have influences on the baby during the first four weeks of development?"

A. Yes. There is all kinds of fragmentary evidence that many things influence the baby during those early stages, but I'll divert away from that to pick up on something else. One of the most interesting things that have come out recently from some work that is being done in Sydney is the influence of high temperatures on the baby during that first period of development. It appears that any infection that causes a high temperature in the mother during that time may adversely affect the baby and cause either congenital anomalies or affect its ultimate intellectual capabilities in some way. Someone told me that members of the MENSA Society in England, a super-IQ, problem-solving club, were predominantly conceived during a winter. That means the chances of their being affected by high temperatures, with an attendant reduction in cognitive potential, would be fairly low. . I believe that some people think that alcohol may have the same effect in that after an alcoholic binge, you run a high temperature of one or two degrees centigrade. Cigarette smoking is shown to affect development of the baby, not just brain development but other areas during development. The problem with all of these; drugs, alcohol, cigarettes, is that gathering the hard evidence is incredibly difficult because of the range of different behaviours in the mothers.

Thank you.

SEMINAR, University of New South Wales
February 24th and 25th, 1979.
FATHERS, MOTHERS AND CHILD WATCHERS.